What Will It Take to End the HIV Epidemic: A Transmission Model of 32 US Cities

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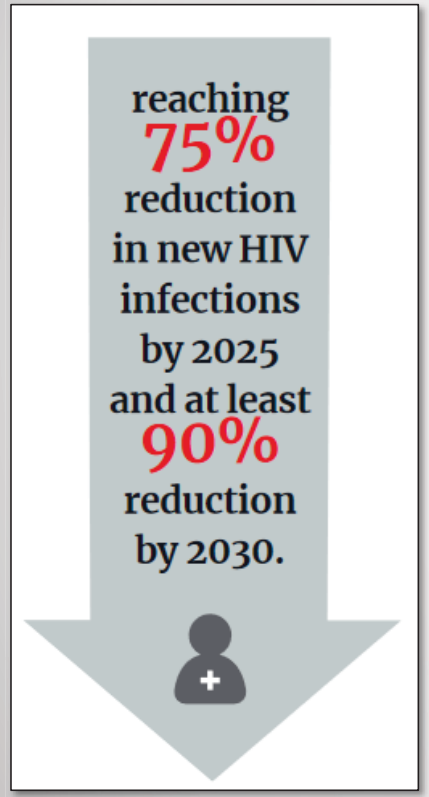
Outline

- The *Ending the HIV Epidemic* Initiative
- Model Structure and Parameters
- Calibration Process
- Results for EHE Goals
- Effects of COVID
- Concluding Thoughts and Future Directions

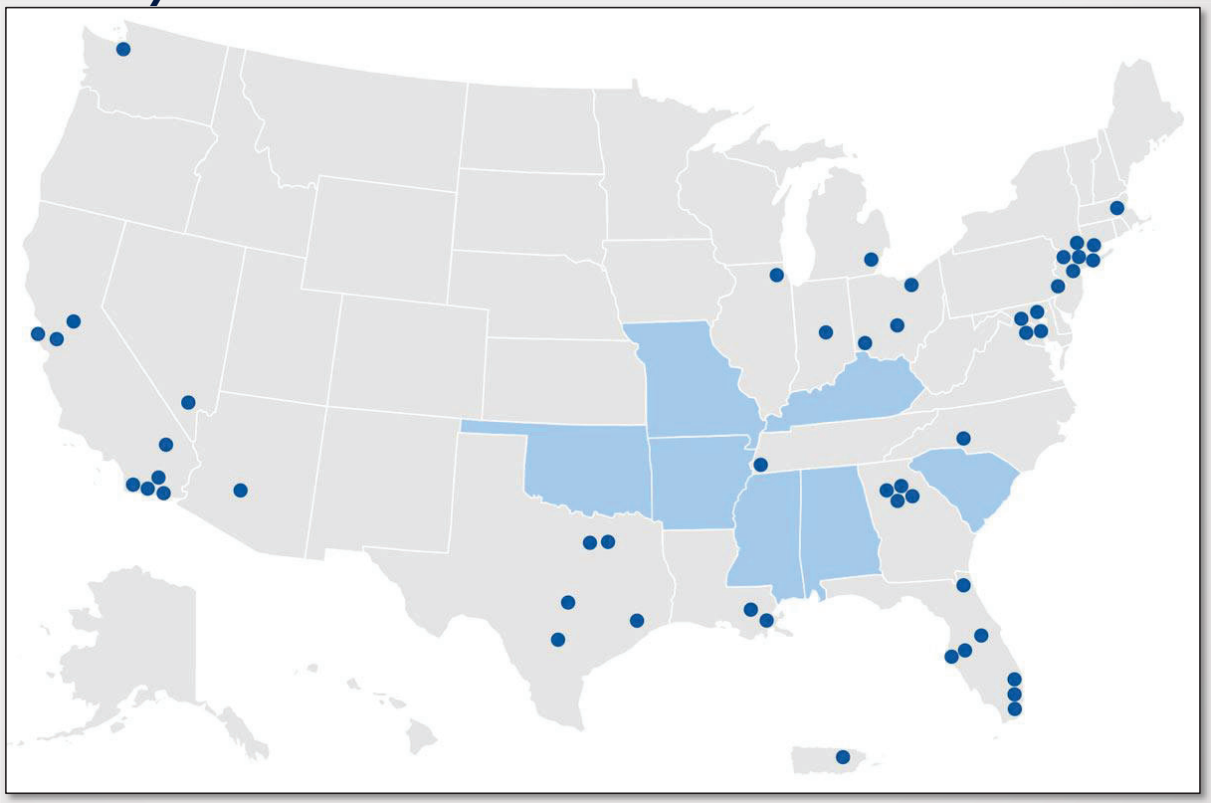
} *Why you can trust us*

The *Ending the HIV Epidemic (EHE)* Initiative

Goal:



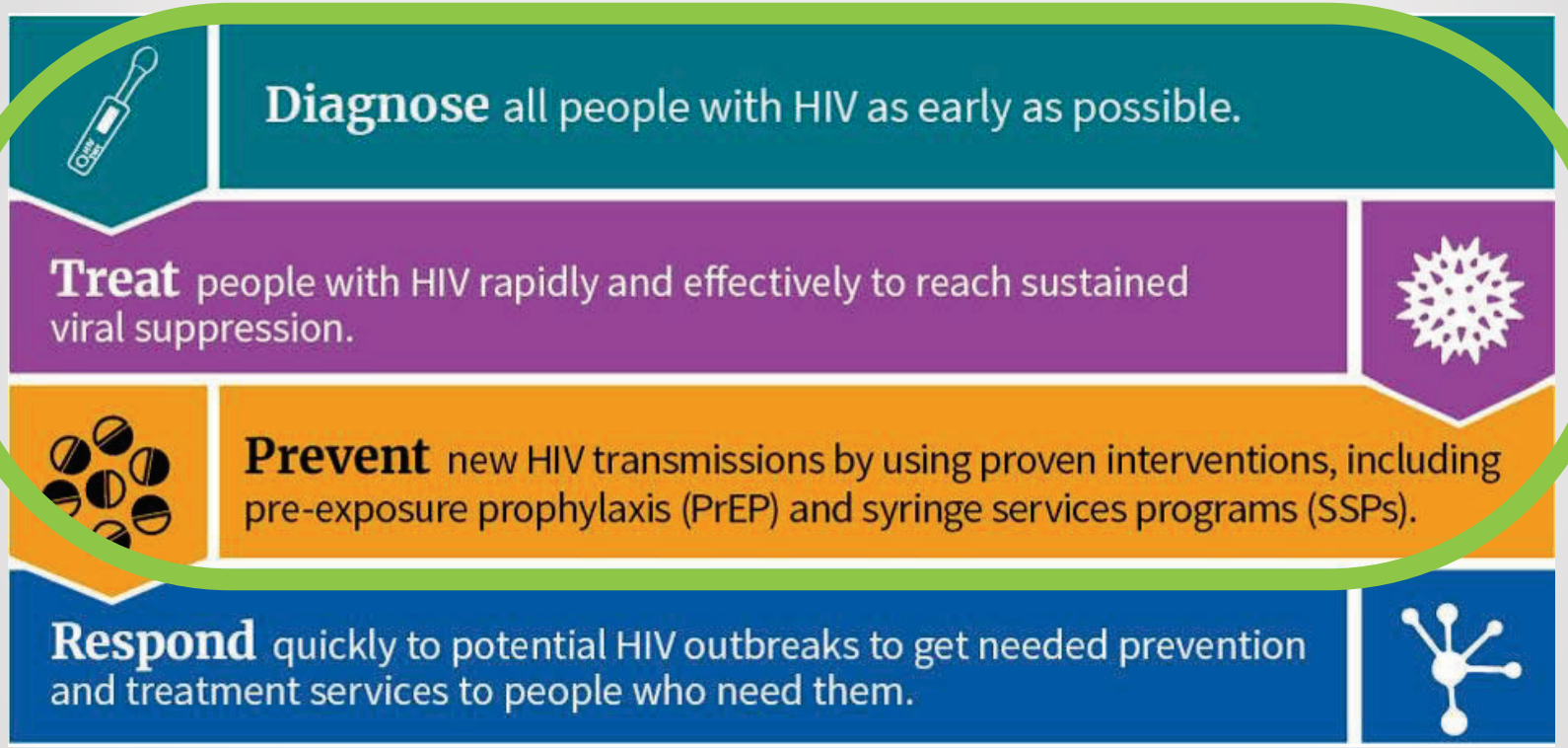
Priority Jurisdictions:



Majority of new cases are among young Black and Hispanic MSM

https://www.cdc.gov/endhiv/docs/ending-HIV-epidemic-overview-508.pdf

EHE "Pillars"



Fauci AS, Redfield RR, Sigounas G, Weahkee MD, Giroir BP. Ending the HIV Epidemic. JAMA. 2019

Objectives

- To what extent do EHE pillars need to be implemented, in what subgroups, and in what combinations, to achieve EHE goals in specific EHE target areas?
  - What frequency of HIV testing?
  - What proportion of PWH suppressed?
  - What proportion of those at risk on PrEP?

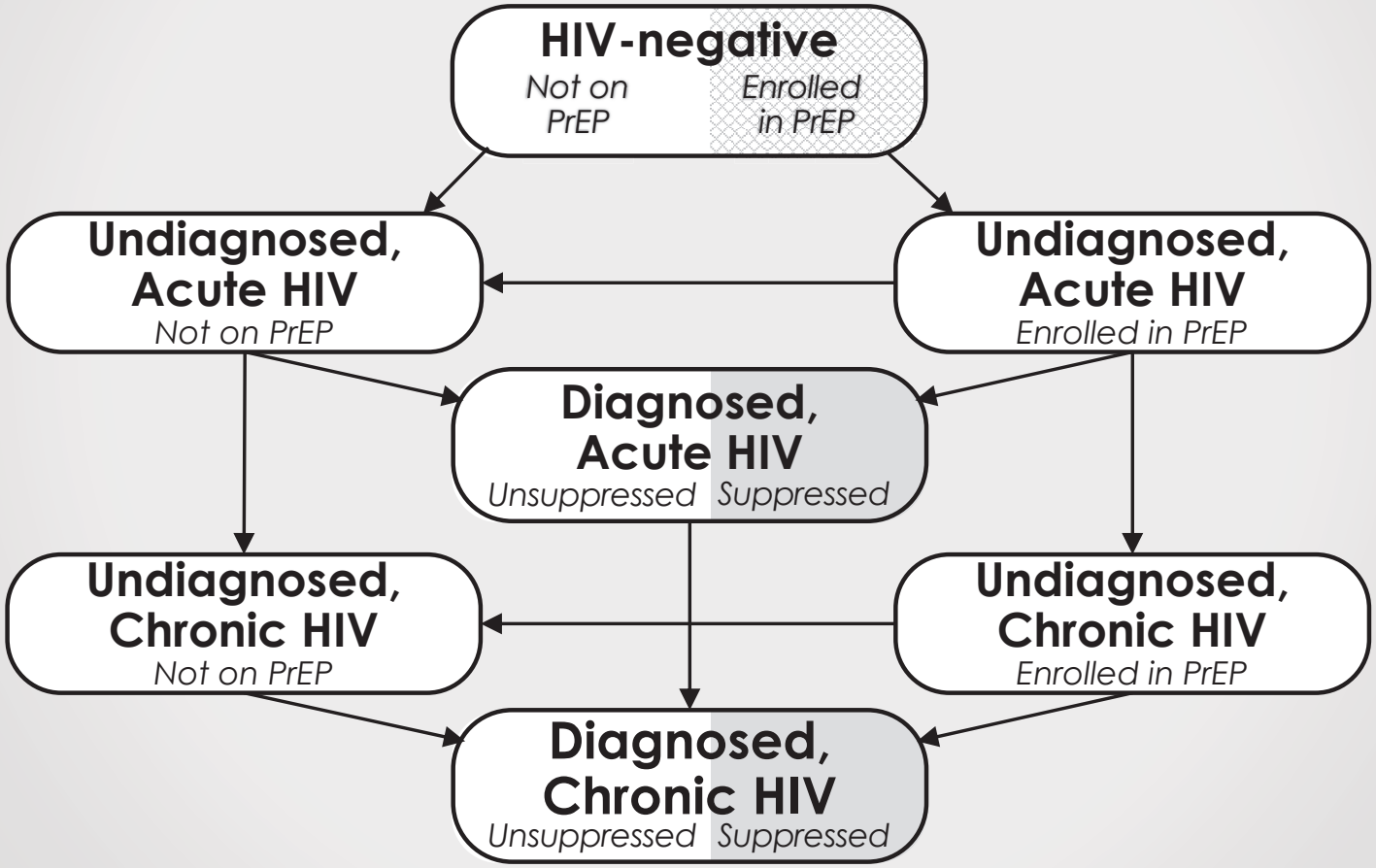
$$\text{Primary outcome} = \frac{incident\ cases\ in\ 2020 - incident\ cases\ in\ 2030}{incident\ cases\ in\ 2020}$$

Compartmental Model

- Represent the population as divided into a number of categories (**compartments**)
- Within each compartment, everyone behaves the same (describing the **average** behavior of those in the compartment)
- Describe the **rate** at which people move between compartments
- Closed system

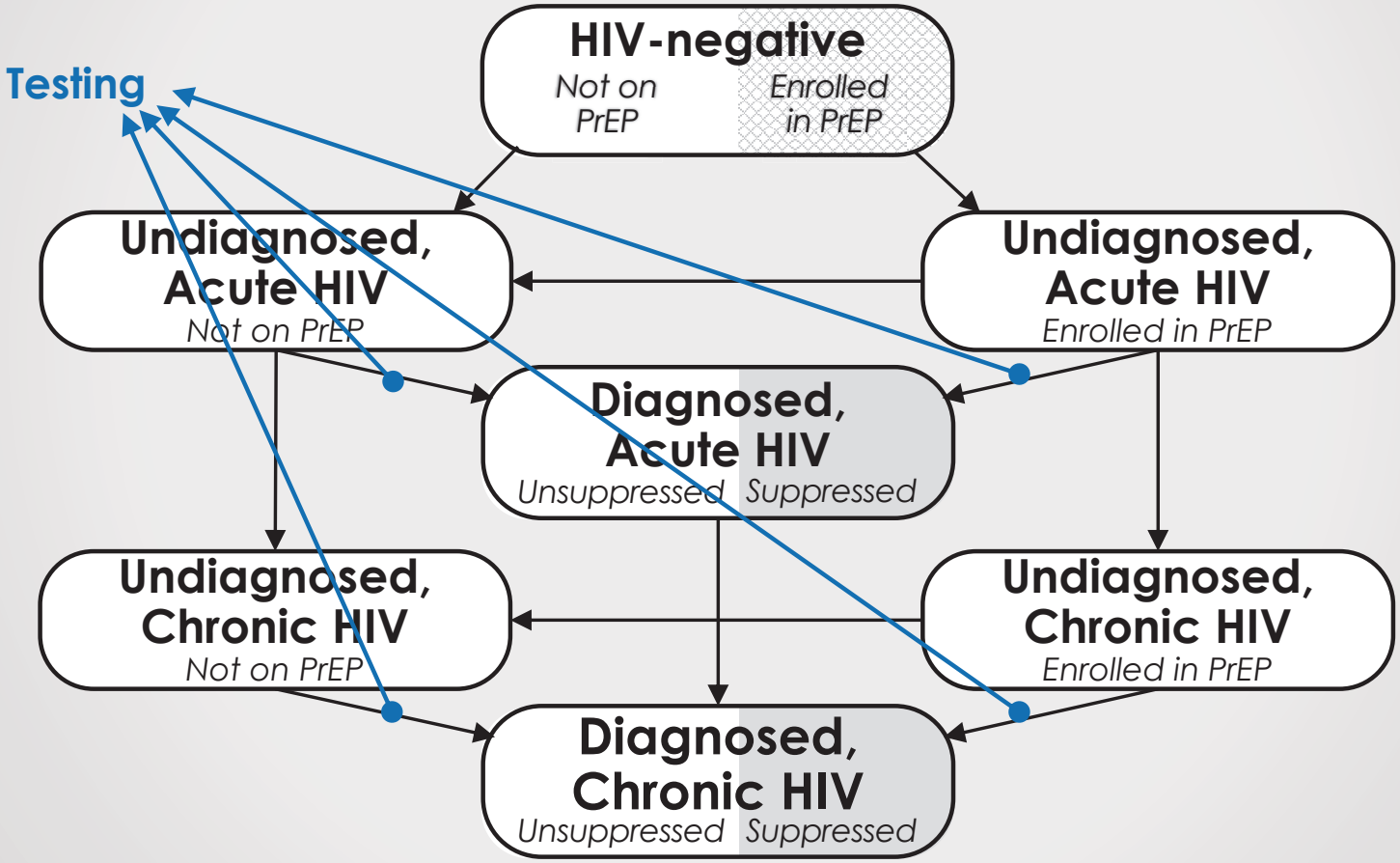
Model Structure

The Johns Hopkins Epidemiologic and Economic Model



Model Structure

The Johns Hopkins Epidemiologic and Economic Model



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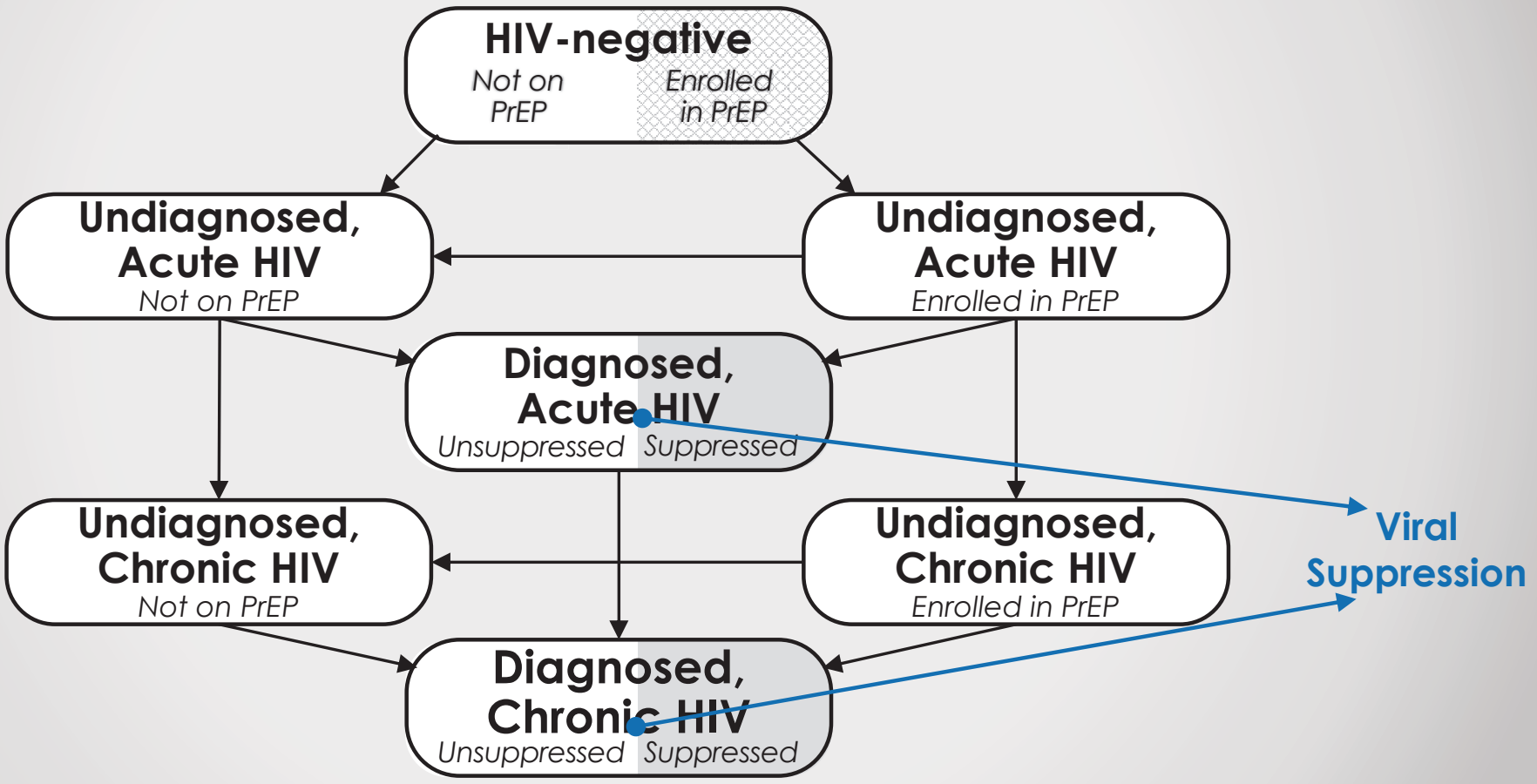

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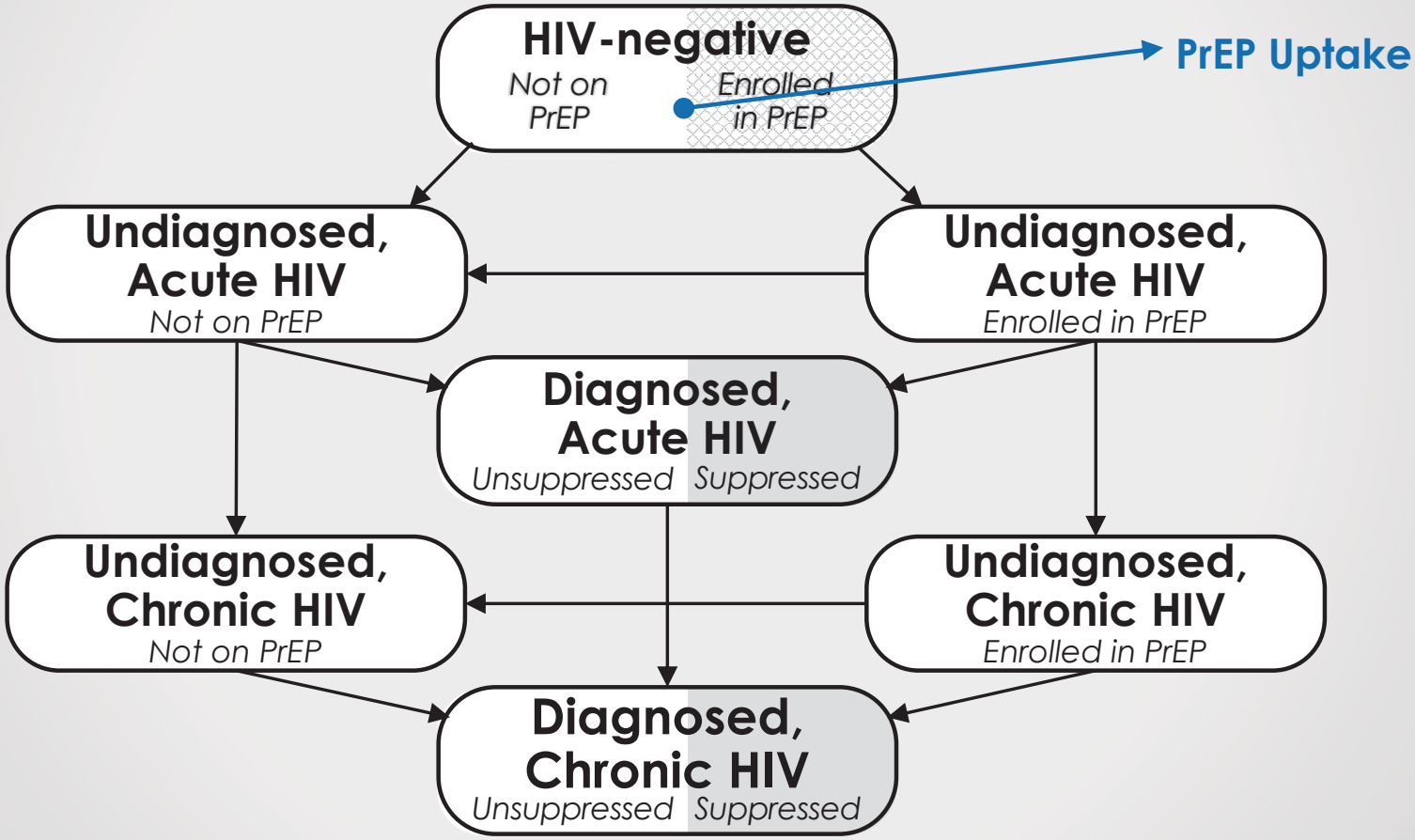

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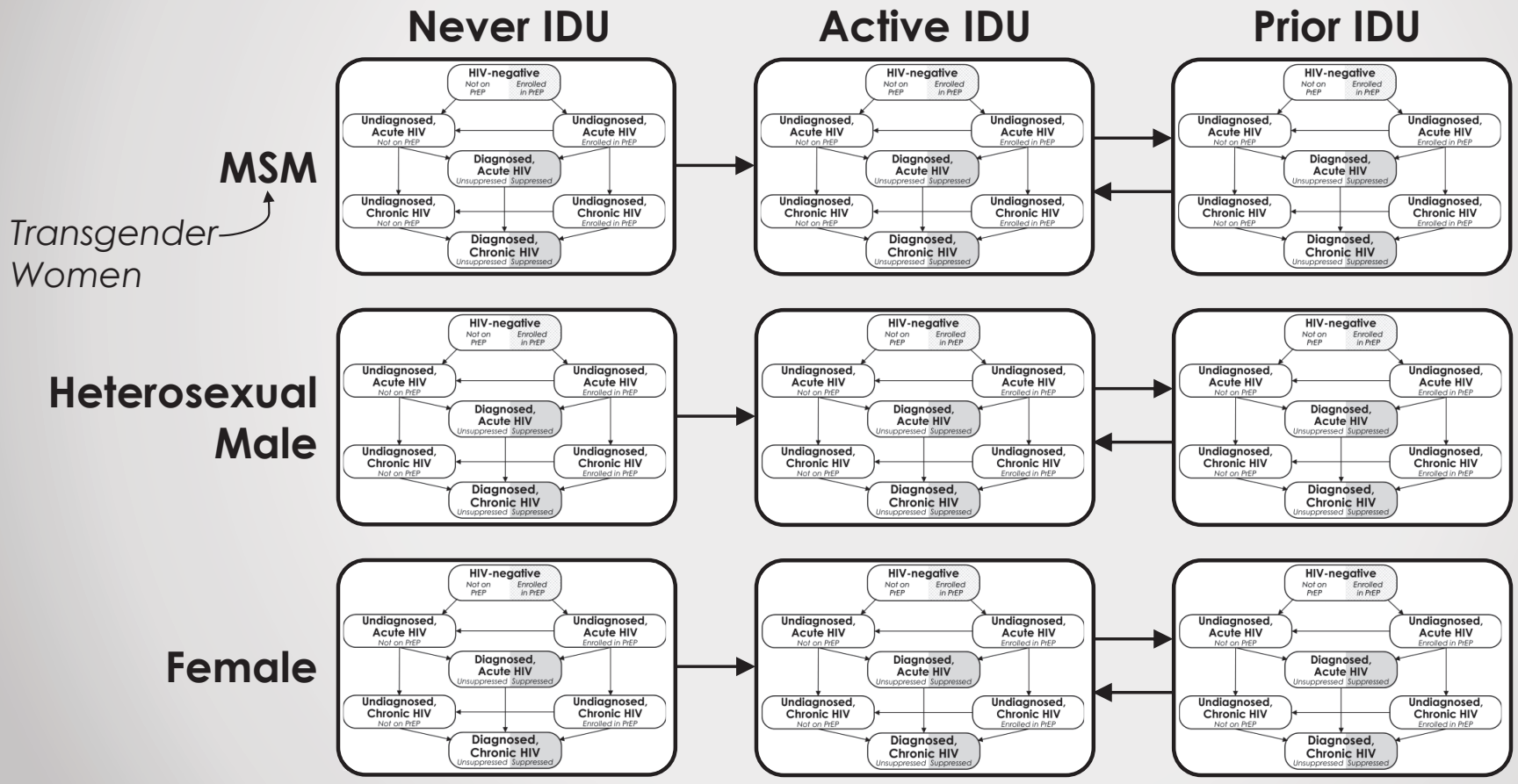
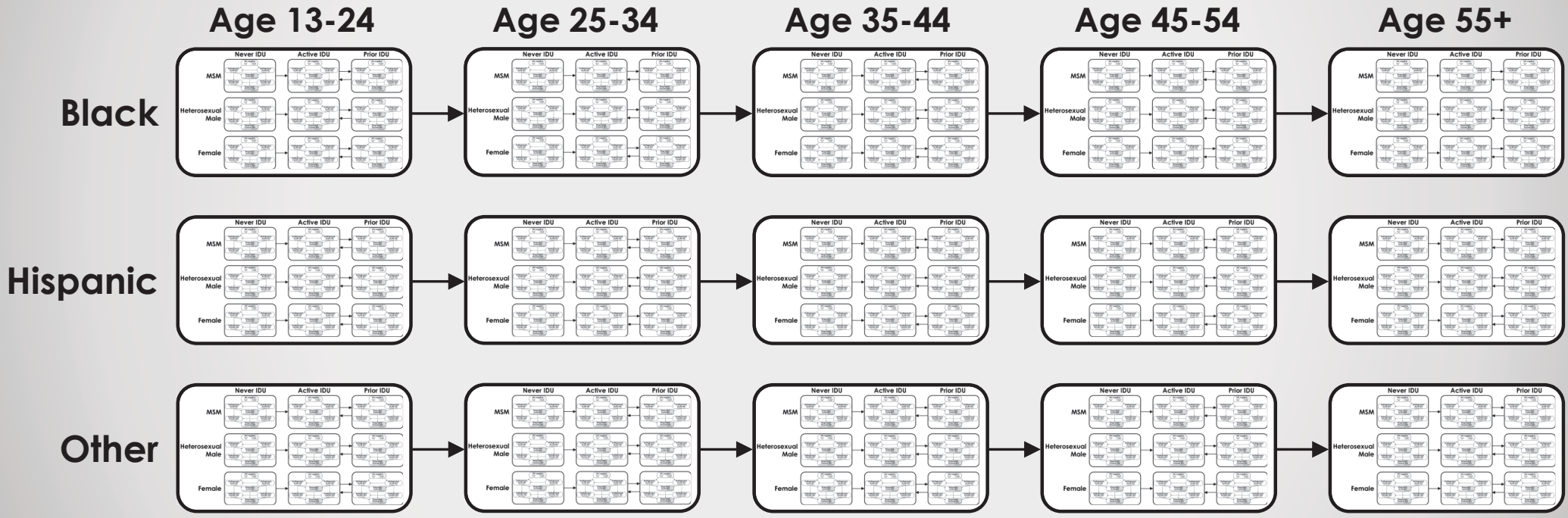


Model Structure

The Johns Hopkins Epidemiologic and Economic Model



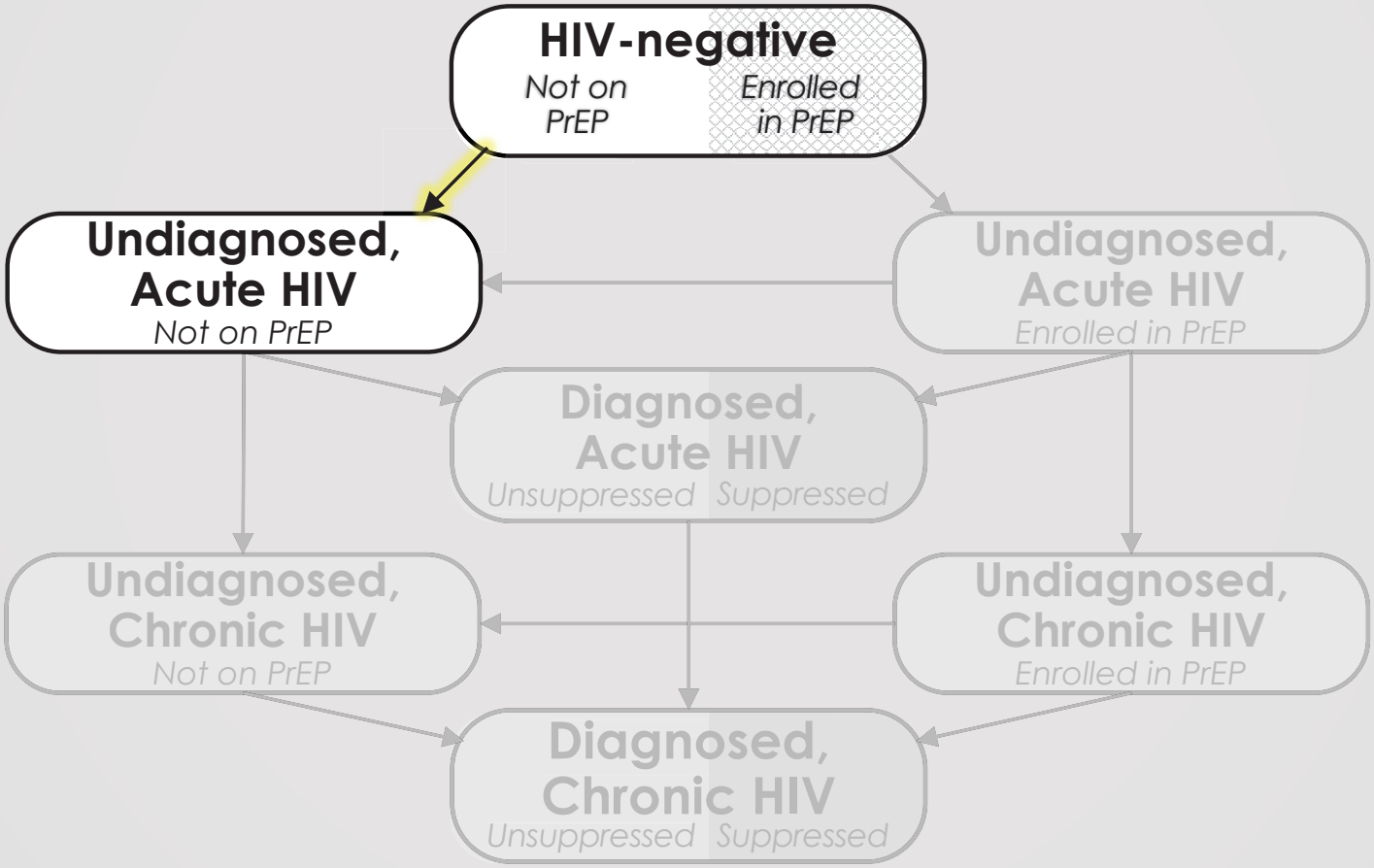
Metropolitan Statistical Areas

San Francisco-Oakland-Berkeley, CA

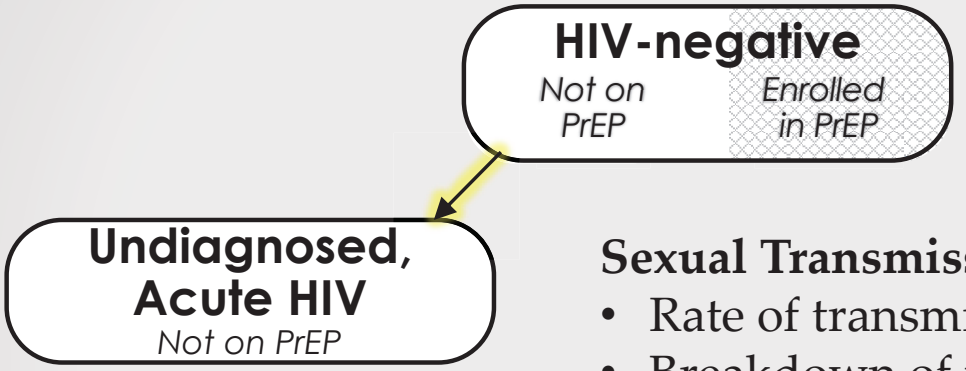
- "Closed system" assumption is more reasonable
- More granular data available from the CDC than the county level

48 EHE counties + DC → 32 MSAs

Model Parameters



Model Parameters



Sexual Transmission:

- Rate of transmission per partnership
- Breakdown of partners by age, race, sex
- Proportion virally suppressed in each partnering stratum
- Variations over time

Transmission via Needle-Sharing

For every stratum of age, race, sex, risk factor

Model Parameters

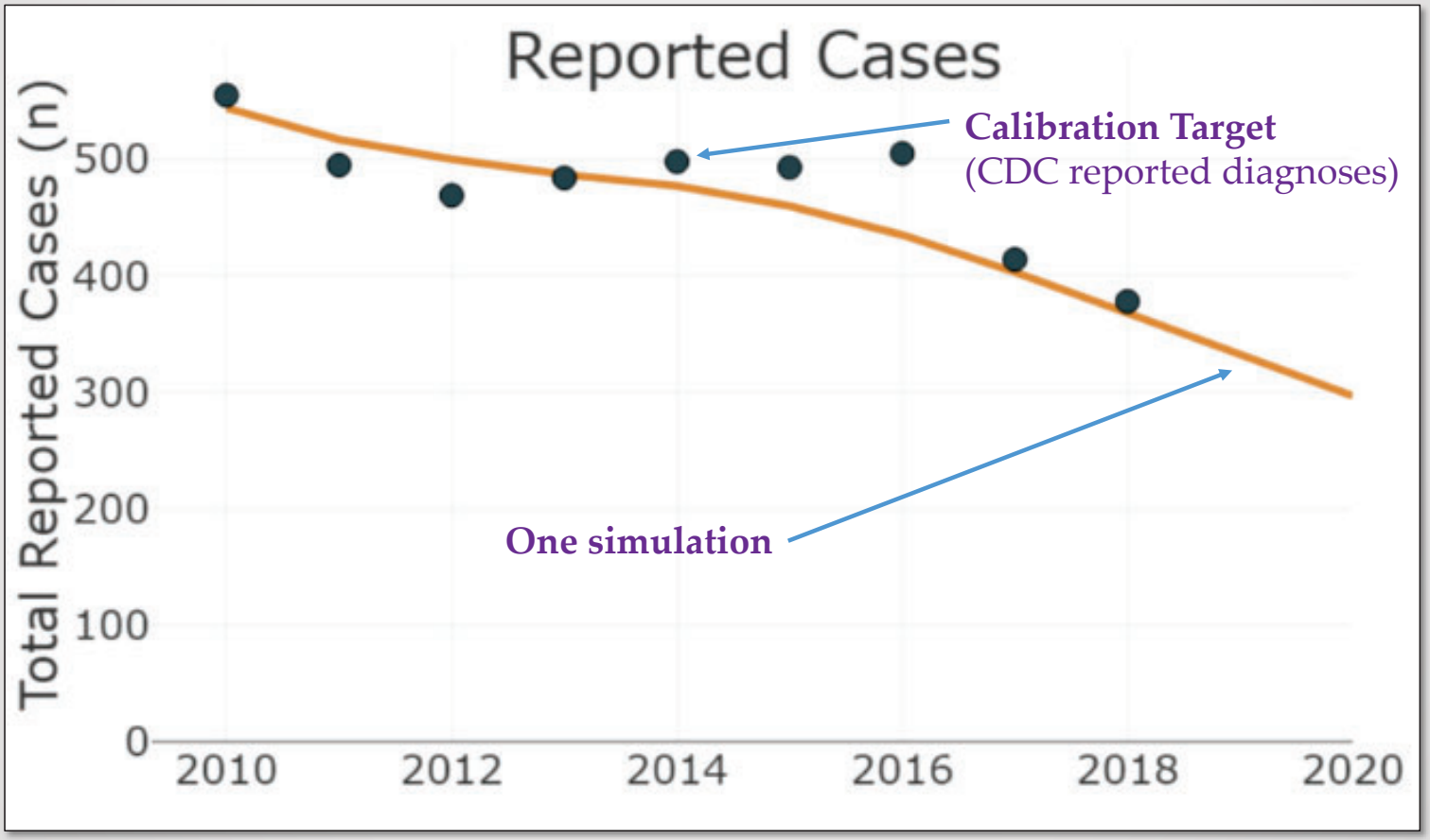
	Parameter	Source
Fixed Parameters	**Population Sizes**	US Census Bureau
	Birth and Death Rates	CDC Wonder
Calibrated Parameters	**Proportion of males who are MSM**	Emory University
	Prevalence of Injection Drug Use	National Survey on Drug Use and Health (NSDUH)
	Partner Assortativity by age, race, sex (sexual and needle-sharing)	Published Literature
	Baseline HIV Testing	Behavioral Risk Factor Surveillance System (BRFSS)
	Baseline Viral Suppression	Local Health Departments
	Baseline PrEP Use	AIDSVu

Calibration

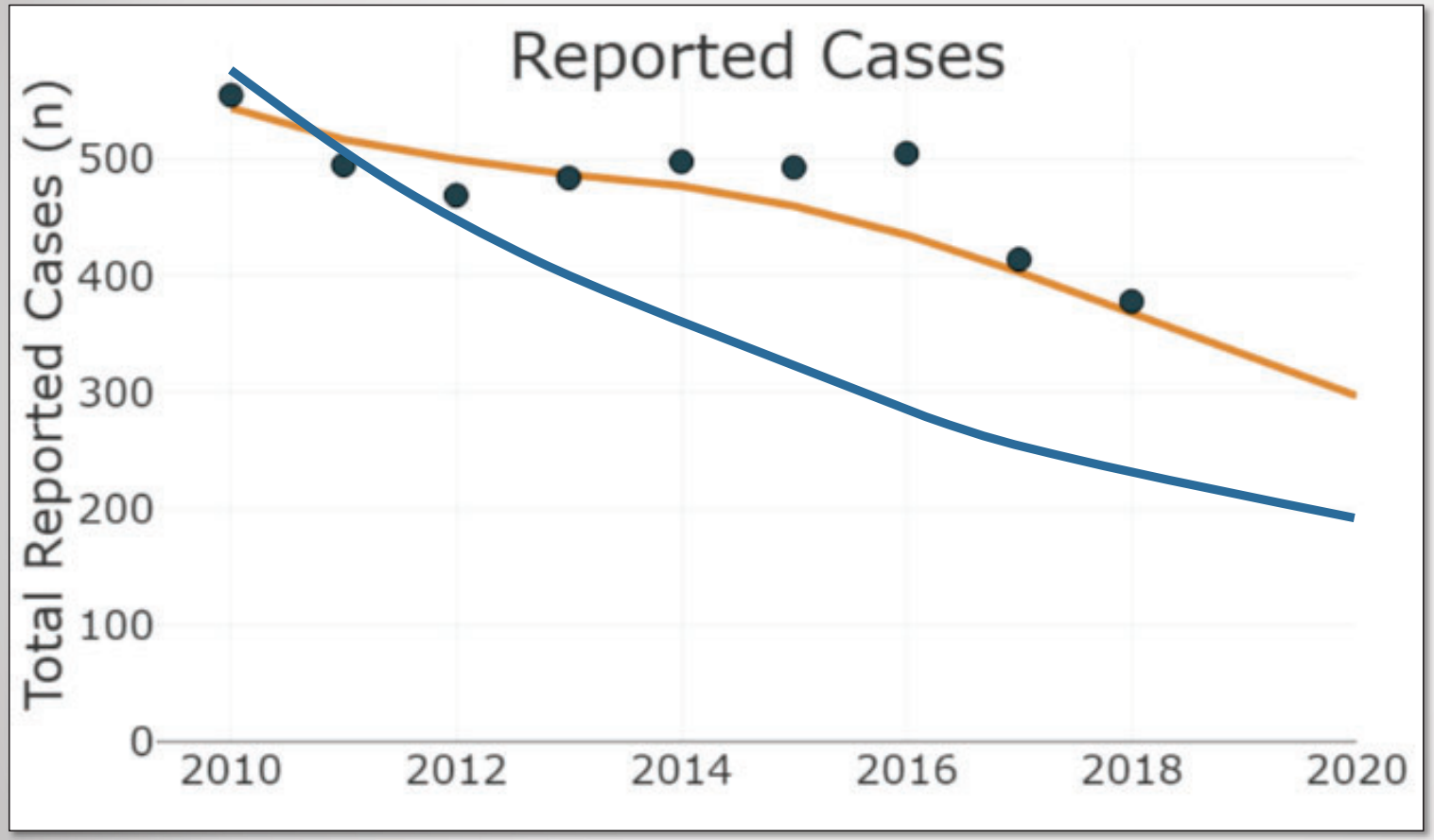
- Identify (for each MSA) which parameter values reproduce the epidemic as we have seen it up to this point
- Reflect our uncertainty by finding a range of different parameter values

Calibration

San Diego-Chula Vista-Carlsbad, CA



Calibration: Likelihood



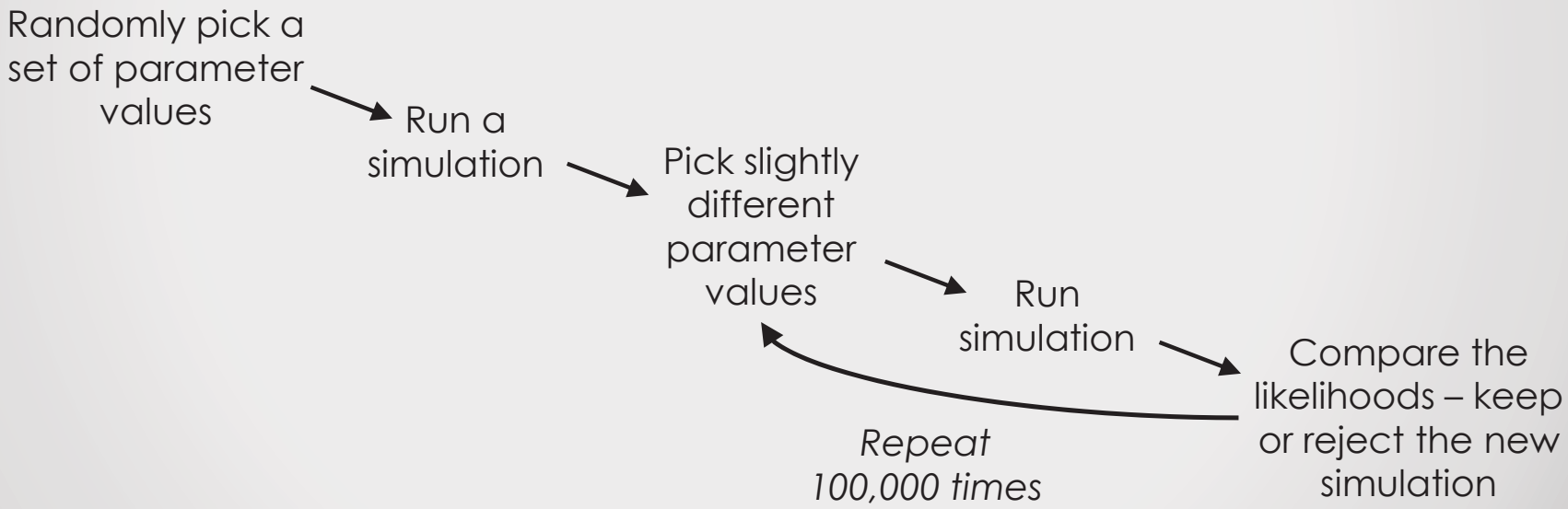
- Function that quantifies how **likely** a simulation is given the observed data
- Use to compare simulations, eg: "sim#1 is **100x** more likely than sim#2"

Calibration Targets

1. Reported diagnoses
2. Estimated prevalence
3. HIV mortality
4. Proportion of PWH who are serostatus-aware
5. Proportion of PWH who are virally suppressed
6. Number of individuals receiving a script for Truvada for PrEP
7. Probability of receiving an HIV test
8. Prevalence of IV drug use
9. Historical reported AIDS cases
10. Historical AIDS mortality

Bayesian Calibration

- Bayesian Markov Chain Monte-Carlo (Adaptive Metropolis Sampling)



Bayesian Calibration

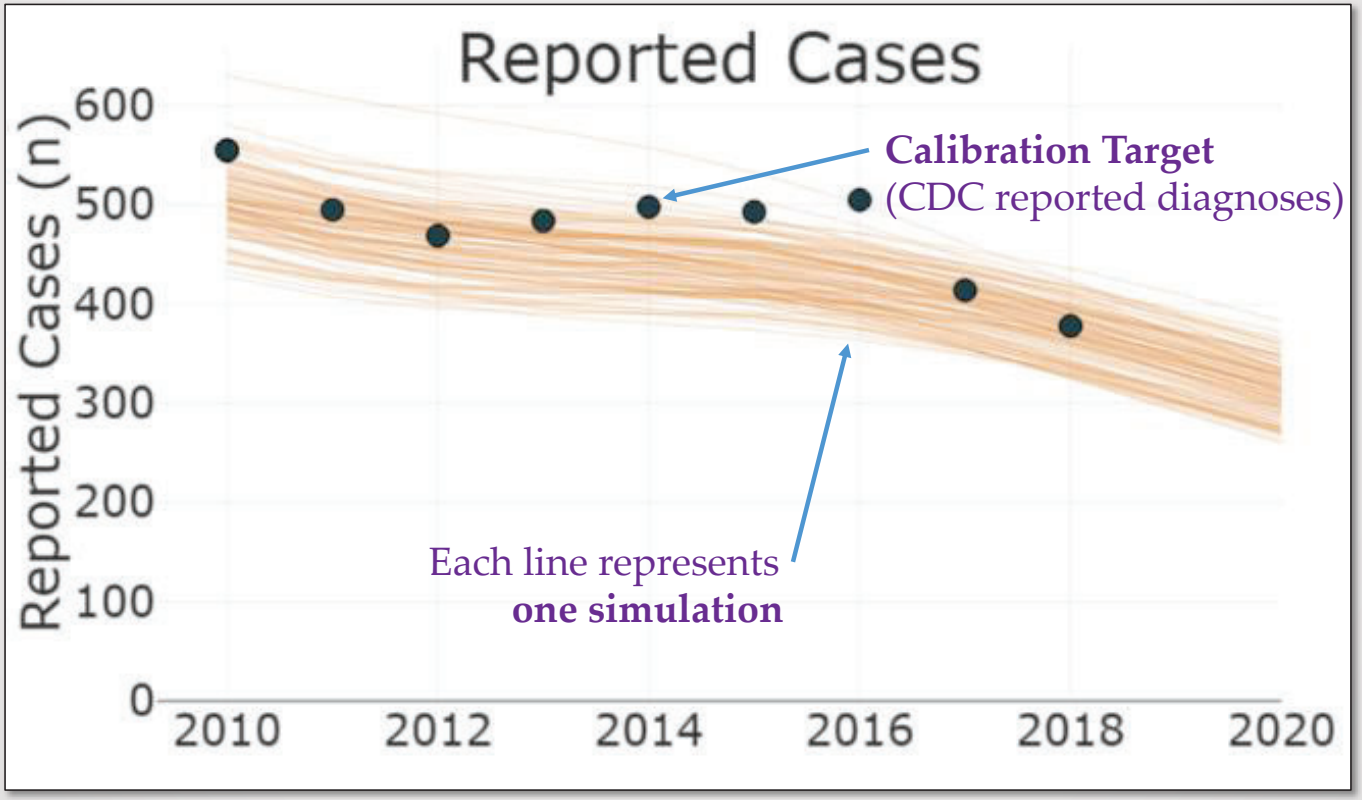
→A set of **simulations** (each with its own parameter values)

- Simulations are included with a probability proportional to its likelihood

- Can calculate statistics for simulation projections
  - Mean, median
  - 95% credible interval

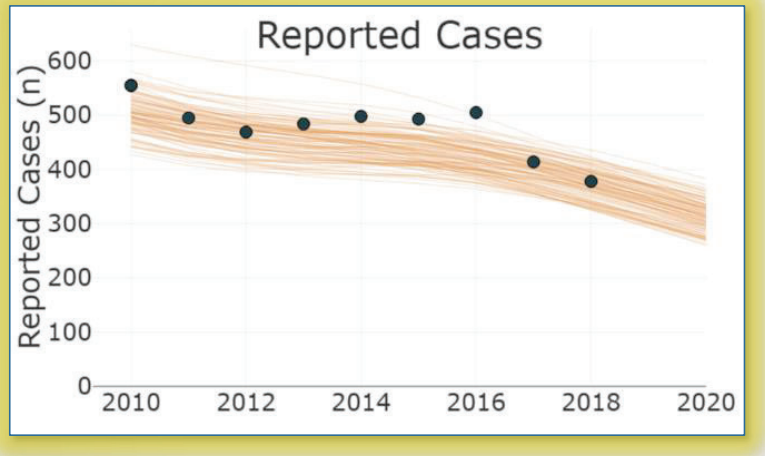
Results: Calibration

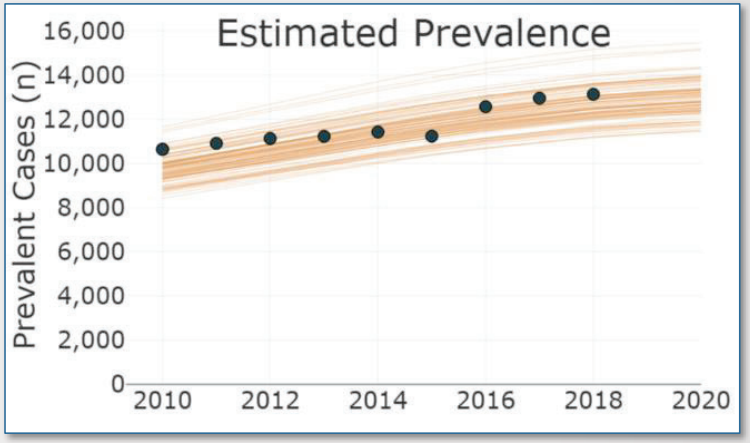
San Diego-Chula Vista-Carlsbad, CA

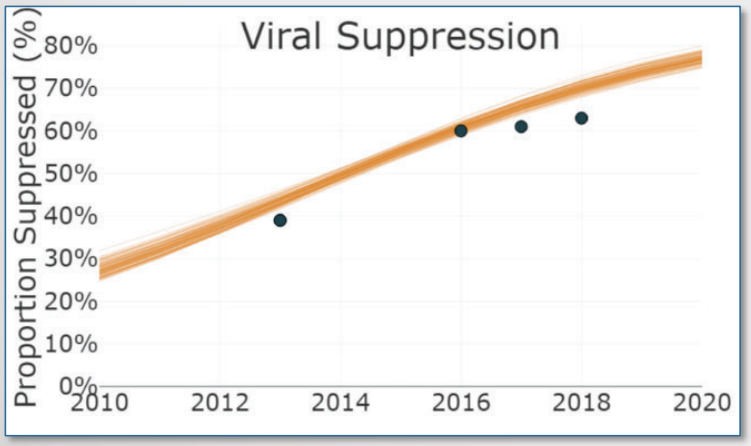


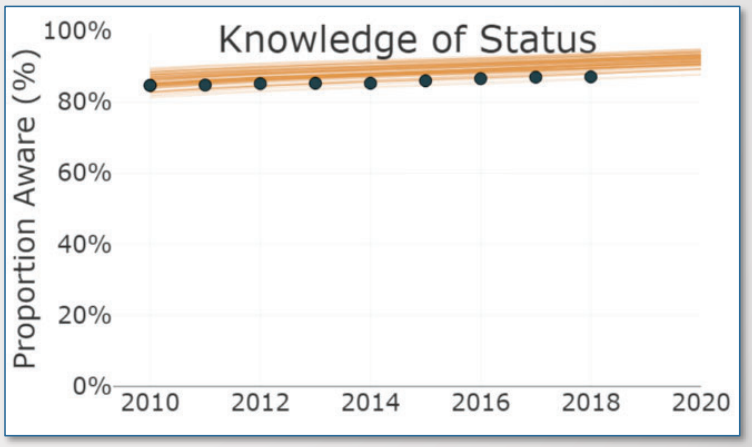
Fojo AT, Schnure M, Kasaie P, Dowdy DW, Shah M. *What Will It Take to End HIV in the United States: A Comprehensive, Local-Level Modeling Study*. Ann Intern Med. 2021.

Results: Calibration

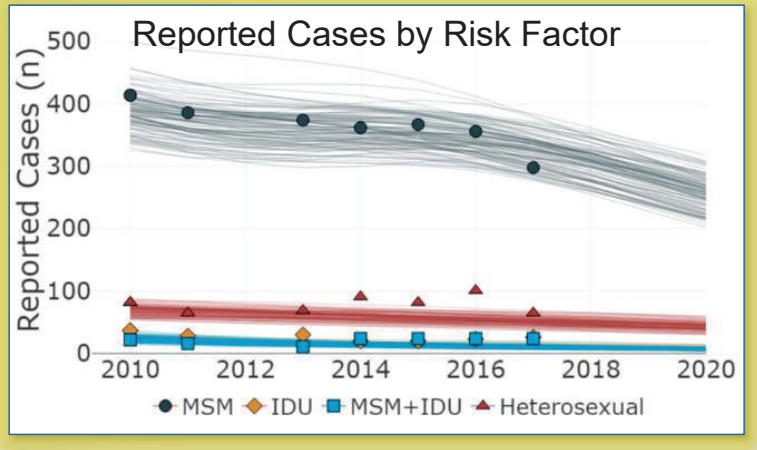


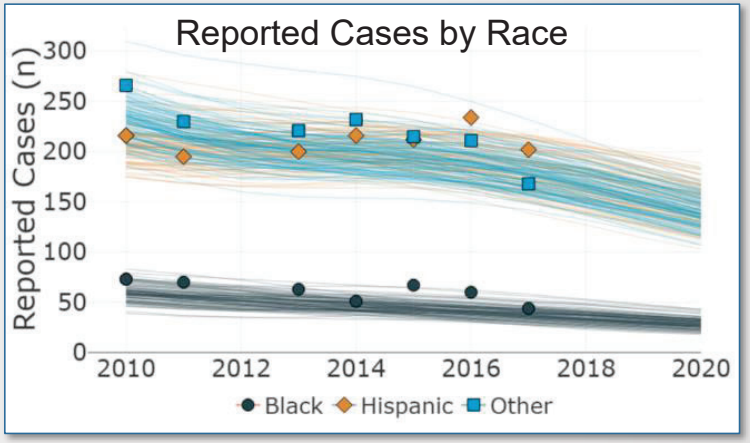


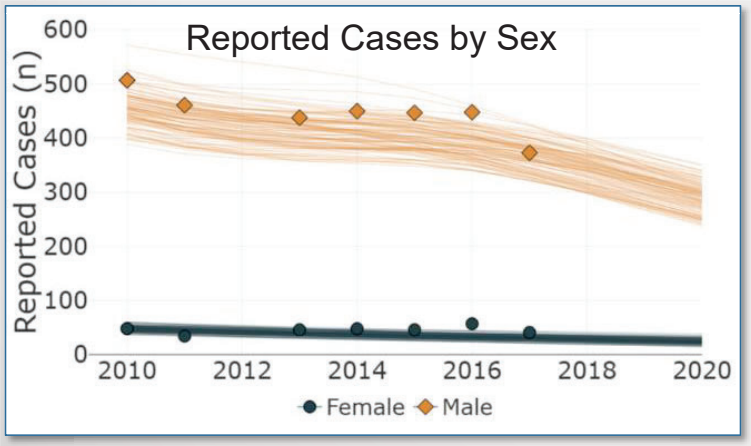


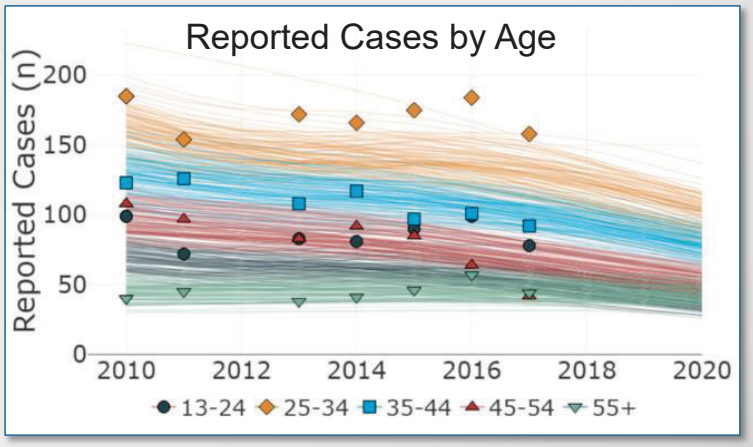


Results: Calibration (stratified)

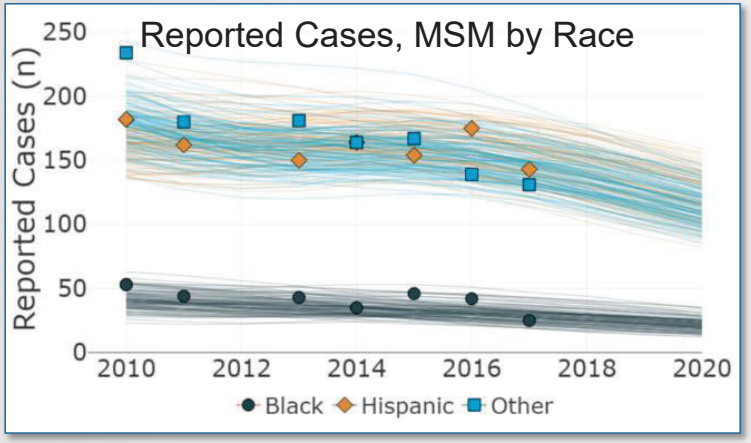


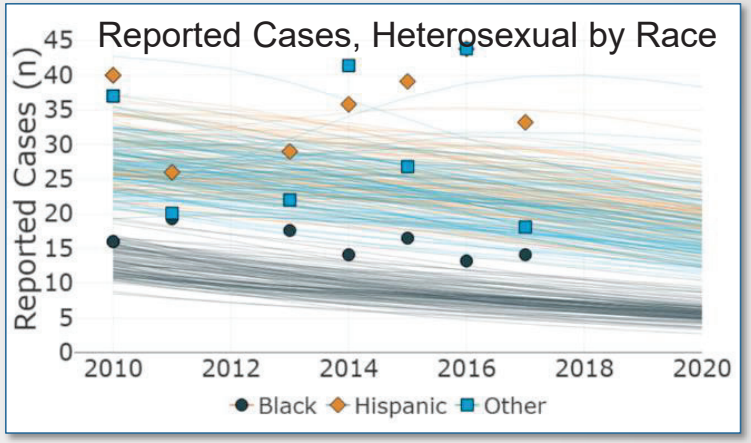


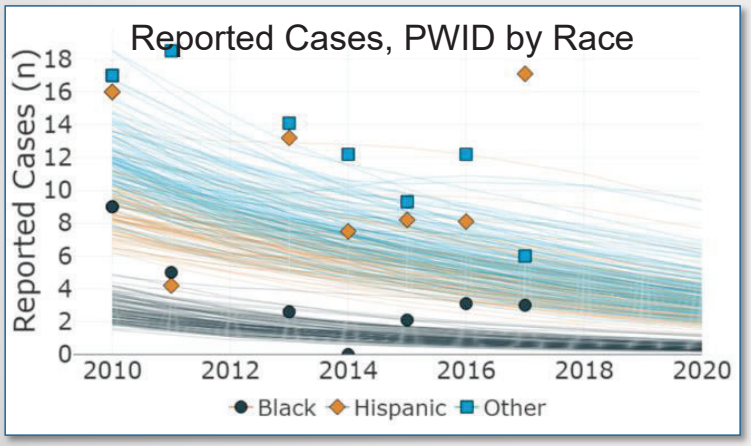


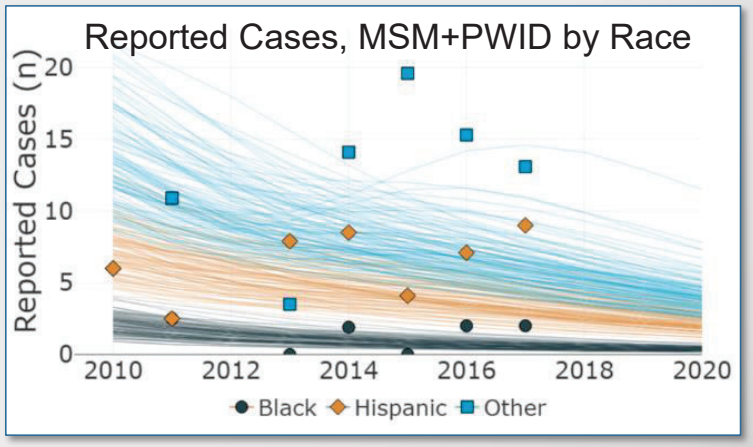


Results: Calibration (stratified x 2)

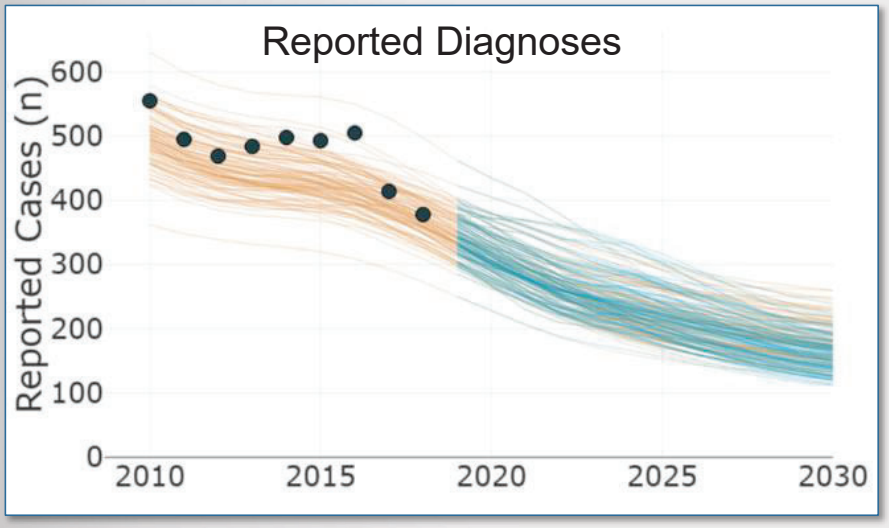


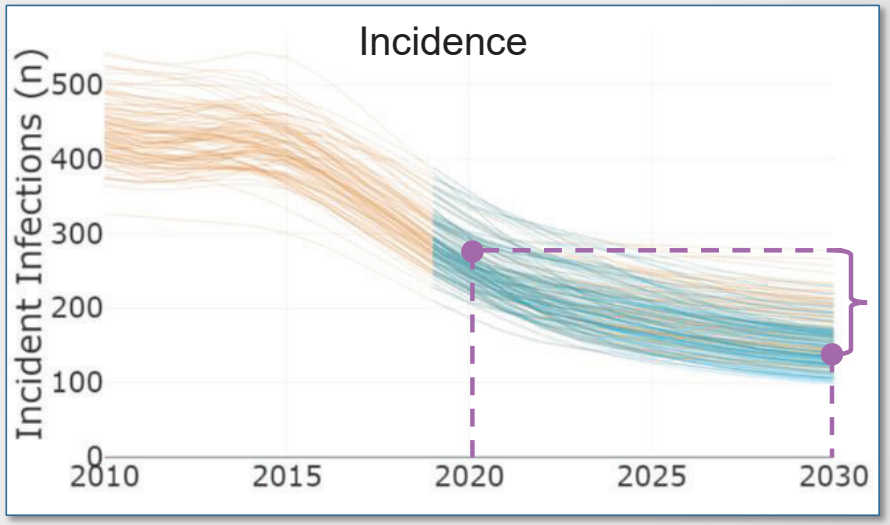






Results: Interventions





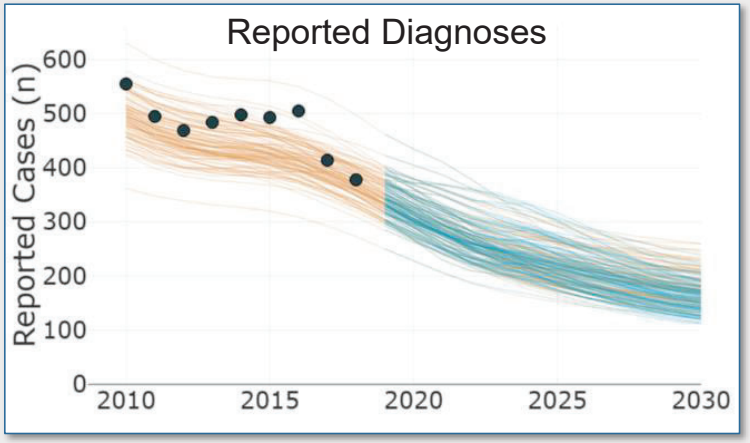
44% [30-58%] Reduction

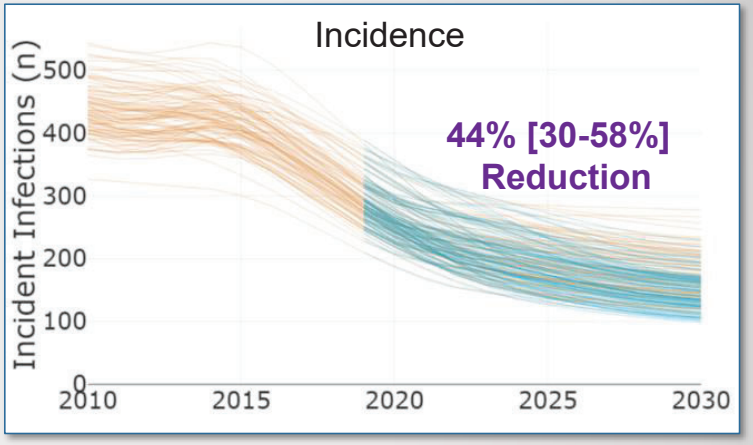
Black and Hispanic MSM and MSM-PWID <35yo:

- HIV Testing yearly on average
- 80% of PWH virally suppressed
- 10% of those at risk in PrEP program

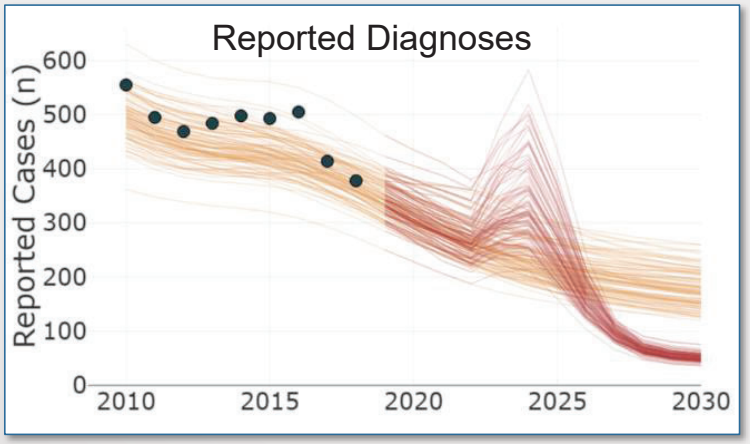
Results: Interventions

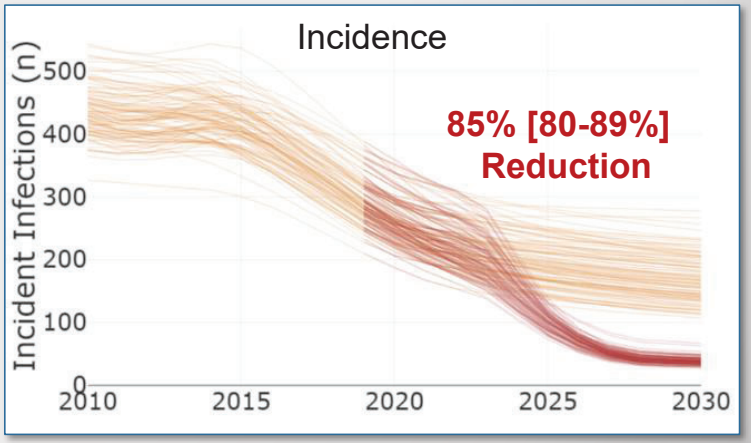
Black and Hispanic MSM and MSM-PWID <35yo:
- HIV Testing yearly
- 80% virally suppressed
- 10% on PrEP





All MSM and all PWID
- HIV Testing 2× per year
- 90% virally suppressed
- 25% on PrEP





Results: Interventions

Black and Hispanic MSM <35yo		No Intervention	1x	2x
	Tests per year		1x	2x
	PrEP Coverage		10%	25%
	Suppression		80%	90%
Non-Black/Hispanic MSM <35yo, Black/Hispanic MSM ≥35yo, All PWID	***Tests per year***		-	2x
	PrEP Coverage		-	25%
	Suppression		-	90%
New York-Newark-Jersey City, NY-NJ-PA		27%	38%	76%
Miami-Fort Lauderdale-Pompano Beach, FL		30%	51%	80%
Los Angeles-Long Beach-Anaheim, CA		13%	39%	88%
Atlanta-Sandy Springs-Alpharetta, GA		7%	34%	81%
Houston-The Woodlands-Sugar Land, TX		13%	42%	85%
Dallas-Fort Worth-Arlington, TX		19%	37%	85%
Chicago-Naperville-Elgin, IL-IN-WI		1%	31%	86%
Washington-Arlington-Alexandria, DC-VA-MD-WV		38%	48%	76%
Philadelphia-Camden-Wilmington, PA-NJ-DE-MD		25%	41%	78%
Orlando-Kissimmee-Sanford, FL		25%	43%	80%
San Francisco-Oakland-Berkeley, CA		34%	44%	84%
Phoenix-Mesa-Chandler, AZ		25%	43%	87%
Tampa-St. Petersburg-Clearwater, FL		24%	37%	86%
Riverside-San Bernardino-Ontario, CA		15%	40%	88%
Detroit-Warren-Dearborn, MI		17%	34%	85%
Baltimore-Columbia-Towson, MD		37%	47%	79%
Las Vegas-Henderson-Paradise, NV		28%	43%	90%
Boston-Cambridge-Newton, MA-NH		26%	27%	84%
San Diego-Chula Vista-Carlsbad, CA		**35%**	**45%**	**85%**
Charlotte-Concord-Gastonia, NC-SC		9%	33%	87%
San Antonio-New Braunfels, TX		12%	38%	86%
Jacksonville, FL		13%	24%	82%
New Orleans-Metairie, LA		30%	39%	81%
Memphis, TN-MS-AR		24%	51%	85%
Seattle-Tacoma-Bellevue, WA		15%	17%	80%
Austin-Round Rock-Georgetown, TX		34%	42%	84%
Indianapolis-Carmel-Anderson, IN		16%	27%	76%
Cincinnati, OH-KY-IN		8%	13%	88%
Columbus, OH		24%	30%	82%
Baton Rouge, LA		20%	37%	67%
Cleveland-Elyria, OH		-2%	20%	89%
Sacramento-Roseville-Folsom, CA		37%	46%	84%
Total		**19%**	**38%**	**83%**

Results: Interventions

		No Intervention	1x	2x
Black and Hispanic MSM <35yo	***Tests per year***		1x	2x
	PrEP Coverage		10%	25%
	Suppression		80%	90%
Non-Black/Hispanic MSM <35yo, Black/Hispanic MSM ≥35yo, All PWID	***Tests per year***		-	2x
	PrEP Coverage		-	25%
	Suppression		-	90%
New York-Newark-Jersey City, NY-NJ-PA		27%	38%	76%
Miami-Fort Lauderdale-Pompano Beach, FL		30%	51%	80%
Los Angeles-Long Beach-Anaheim, CA		13%	39%	88%
Atlanta-Sandy Springs-Alpharetta, GA		7%	34%	81%
Houston-The Woodlands-Sugar Land, TX		13%	42%	85%
Dallas-Fort Worth-Arlington, TX		19%	37%	85%
Chicago-Naperville-Elgin, IL-IN-WI		1%	31%	86%
Washington-Arlington-Alexandria, DC-VA-MD-WV		38%	48%	76%
Philadelphia-Camden-Wilmington, PA-NJ-DE-MD		25%	41%	78%
Orlando-Kissimmee-Sanford, FL		25%	43%	80%
…				
San Diego-Chula Vista-Carlsbad, CA		**35%**	**45%**	**85%**
…				
Total		**19%**	**38%**	**83%**

Single-Modality + Marginal Interventions

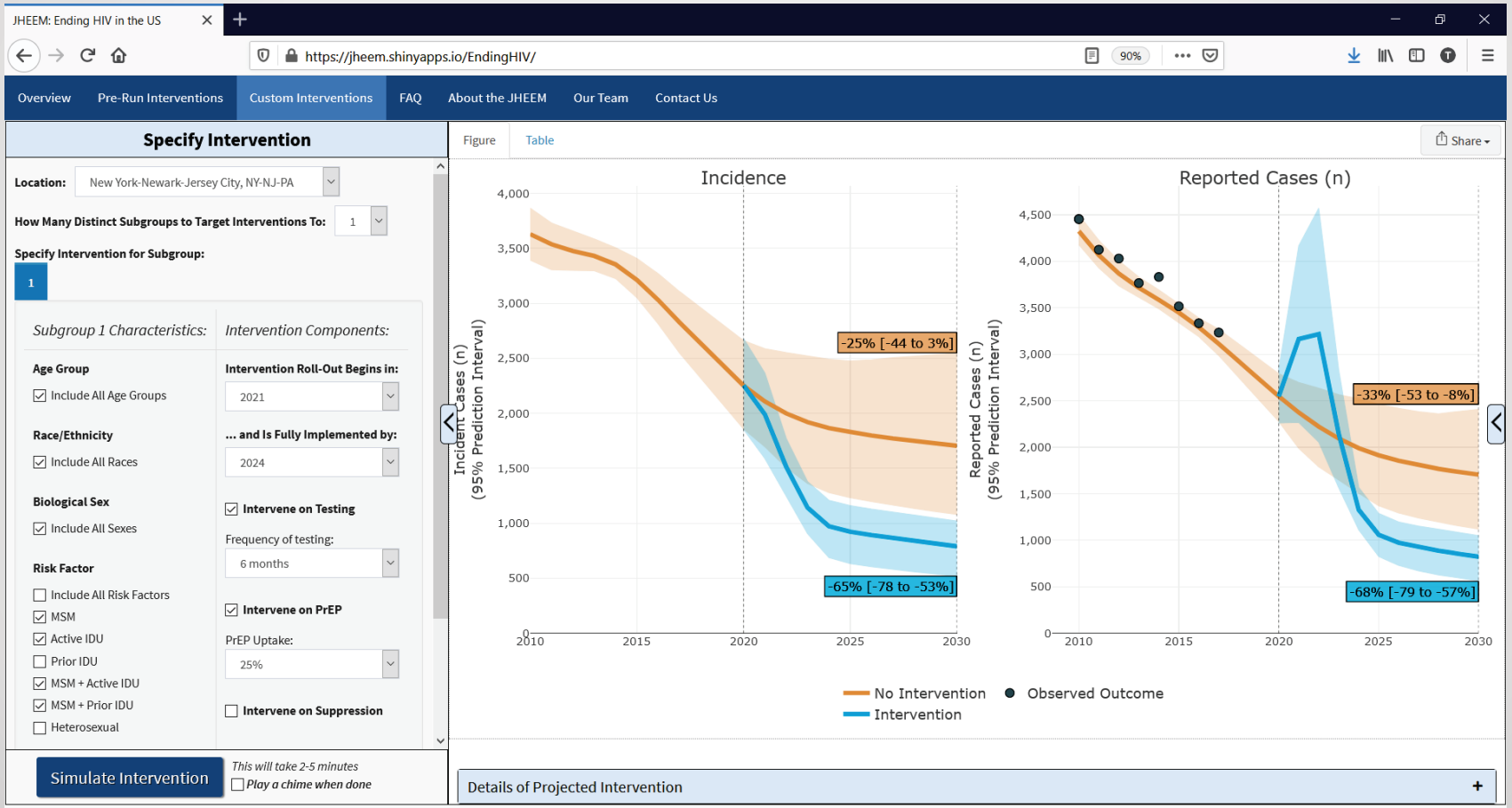
		No Intervention	Marginal Improvement*			
Black and Hispanic MSM <35yo	***Tests per year***			2x	-	-
	PrEP Coverage			-	25%	-
	Suppression			-	-	90%
Non-Black/Hispanic MSM <35yo, Black/Hispanic MSM ≥35yo, All PWID	***Tests per year***			2x	-	-
	PrEP Coverage			-	25%	-
	Suppression			-	-	90%
All Heterosexuals	***Tests per year***			1x	-	-
	PrEP Coverage			-	25%	-
	Suppression			-	-	90%
New York-Newark-Jersey City, NY-NJ-PA		27%	62%	55%	43%	59%
Miami-Fort Lauderdale-Pompano Beach, FL		30%	60%	68%	52%	58%
Los Angeles-Long Beach-Anaheim, CA		13%	50%	56%	43%	60%
Atlanta-Sandy Springs-Alpharetta, GA		7%	37%	24%	32%	76%
Houston-The Woodlands-Sugar Land, TX		13%	48%	57%	45%	57%
Dallas-Fort Worth-Arlington, TX		19%	55%	51%	47%	65%
Chicago-Naperville-Elgin, IL-IN-WI		1%	34%	32%	25%	74%
Washington-Arlington-Alexandria, DC-VA-MD-WV		38%	65%	58%	55%	67%
Philadelphia-Camden-Wilmington, PA-NJ-DE-MD		25%	55%	49%	48%	72%
Orlando-Kissimmee-Sanford, FL		25%	56%	59%	50%	64%
…						
San Diego-Chula Vista-Carlsbad, CA		**35%**	**67%**	**67%**	**59%**	**59%**
…						
Total		**19%**	**53%**	**55%**	**46%**	**60%**

"Marginal Improvement" = Testing 1.25× as often, 5% more on PrEP, 10% more suppressed

Multi-Modality Interventions

		No Intervention													
Black and Hispanic MSM <35yo	***Tests per year***		1x		2x		1x		2x		1x		2x		
	PrEP Coverage		10%		25%		10%		25%		10%		25%		
	Suppression		80%		90%		80%		90%		80%		90%		
Non-Black/Hispanic MSM <35yo, Black/Hispanic MSM ≥35yo, All PWID	***Tests per year***		-				1x		2x		1x		2x		
	PrEP Coverage		-				10%		25%		10%		25%		
	Suppression		-				80%		90%		80%		90%		
All Heterosexuals	***Tests per year***		-								½ x		1x		
	PrEP Coverage		-								10%		25%		
	Suppression		-								80%		90%		
New York-Newark-Jersey City, NY-NJ-PA		27%	38%	43%	45%	50%	53%	59%	63%	76%	56%	63%	68%	82%	
Miami-Fort Lauderdale-Pompano Beach, FL		30%	51%	56%	59%	62%	66%	71%	74%	80%	73%	79%	83%	91%	
Los Angeles-Long Beach-Anaheim, CA		13%	39%	45%	49%	53%	67%	73%	78%	88%	68%	74%	79%	90%	
Atlanta-Sandy Springs-Alpharetta, GA		7%	34%	38%	42%	47%	60%	64%	69%	81%	65%	70%	75%	88%	
Houston-The Woodlands-Sugar Land, TX		13%	42%	49%	53%	57%	66%	72%	76%	85%	70%	76%	81%	90%	
Dallas-Fort Worth-Arlington, TX		19%	37%	42%	46%	51%	60%	67%	73%	85%	62%	69%	75%	88%	
Chicago-Naperville-Elgin, IL-IN-WI		1%	31%	37%	39%	43%	68%	73%	76%	86%	72%	77%	81%	90%	
Washington-Arlington-Alexandria, DC-VA-MD-WV		38%	48%	52%	55%	58%	57%	63%	67%	76%	61%	68%	73%	84%	
Philadelphia-Camden-Wilmington, PA-NJ-DE-MD		25%	41%	46%	50%	53%	59%	66%	70%	78%	67%	74%	79%	89%	
Orlando-Kissimmee-Sanford, FL		25%	43%	48%	52%	55%	61%	68%	71%	80%	69%	76%	81%	90%	
…															
San Diego-Chula Vista-Carlsbad, CA		**35%**	**45%**	**49%**	**52%**	**54%**	**62%**	**70%**	**75%**	**85%**	**64%**	**71%**	**77%**	**87%**	
…															
Total		**19%**	**38%**	**43%**	**47%**	**50%**	**62%**	**69%**	**73%**	**83%**	**66%**	**73%**	**78%**	**88%**	

Web Tool (www.jheem.org)



Conclusions (EHE)

- The EHE goals will be difficult to achieve, generally requiring, sustained, intensive interventions applied across the whole population
- Targeting high-risk subgroups can yield substantial reductions in incidence, but is not going to get to 90%
- Modestly improving testing, PrEP uptake, and viral suppression can yield substantial reductions in incidence, but is not going to get to 90%
- There is substantial local-level variation in the effects of interventions

The COVID-19 Pandemic

- Allow the pandemic to affect four parameters:

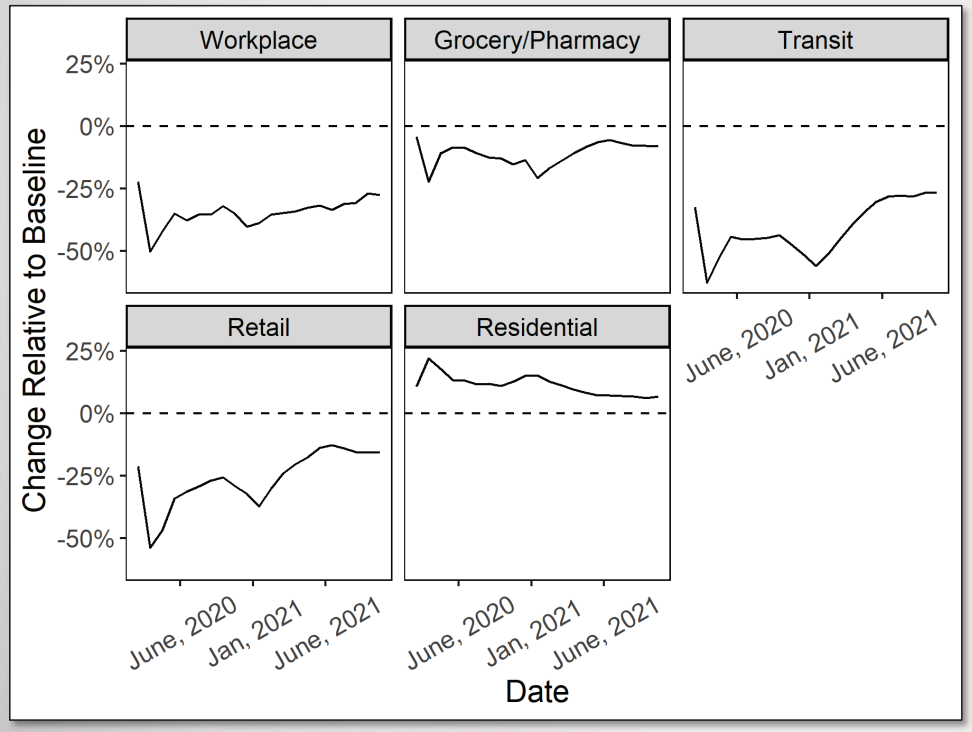
Sexual Transmission Rates	0 – 50% reduction
Viral Suppression	0 – 40% reduction
HIV Testing Rates	0 – 50% reduction
PrEP Use	0 – 30% reduction

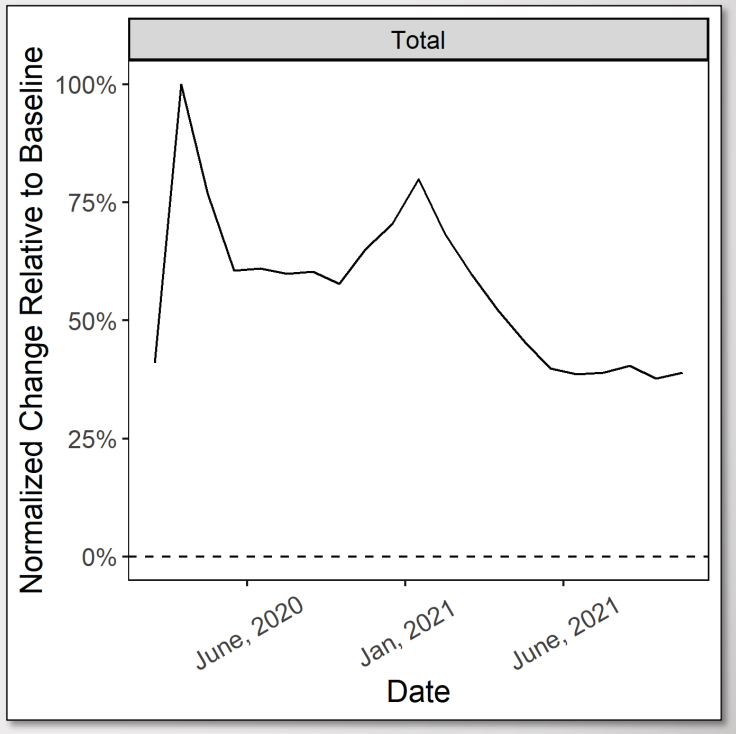
At outset of the pandemic

The COVID-19 Pandemic

Google Community Mobility Reports

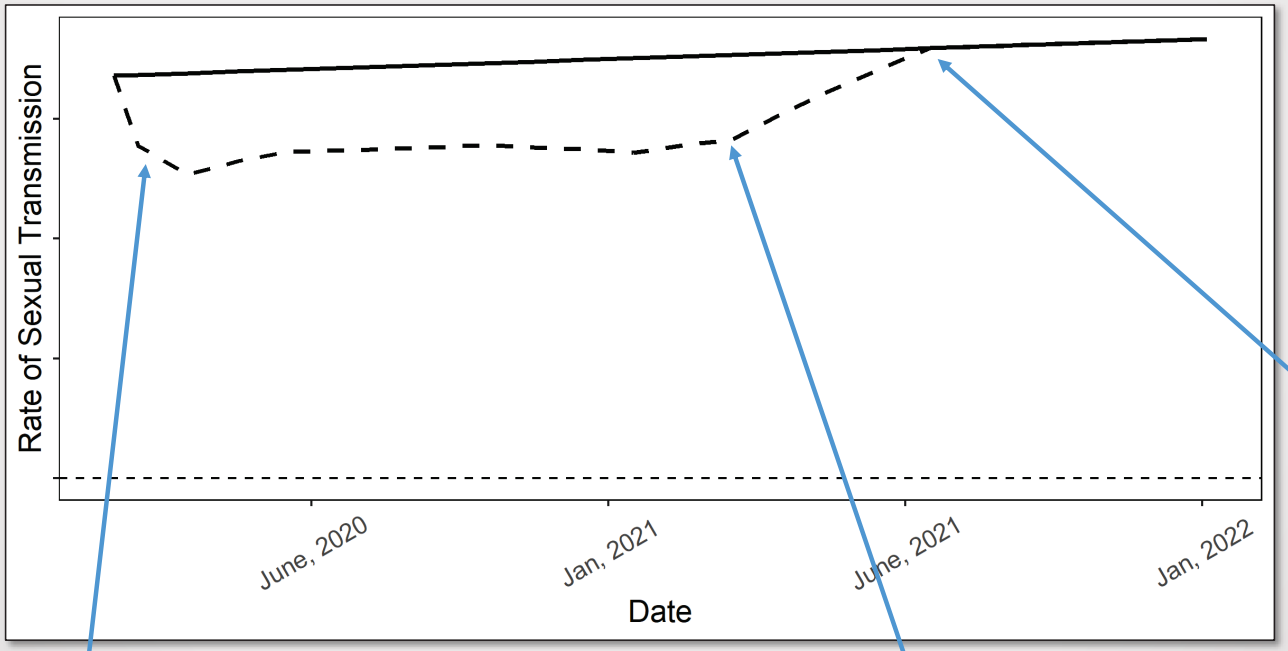
- Index the pandemic's effects (partially) to mobility data





The COVID-19 Pandemic

- Example **25%** maximal reduction of **Sexual Transmission:**



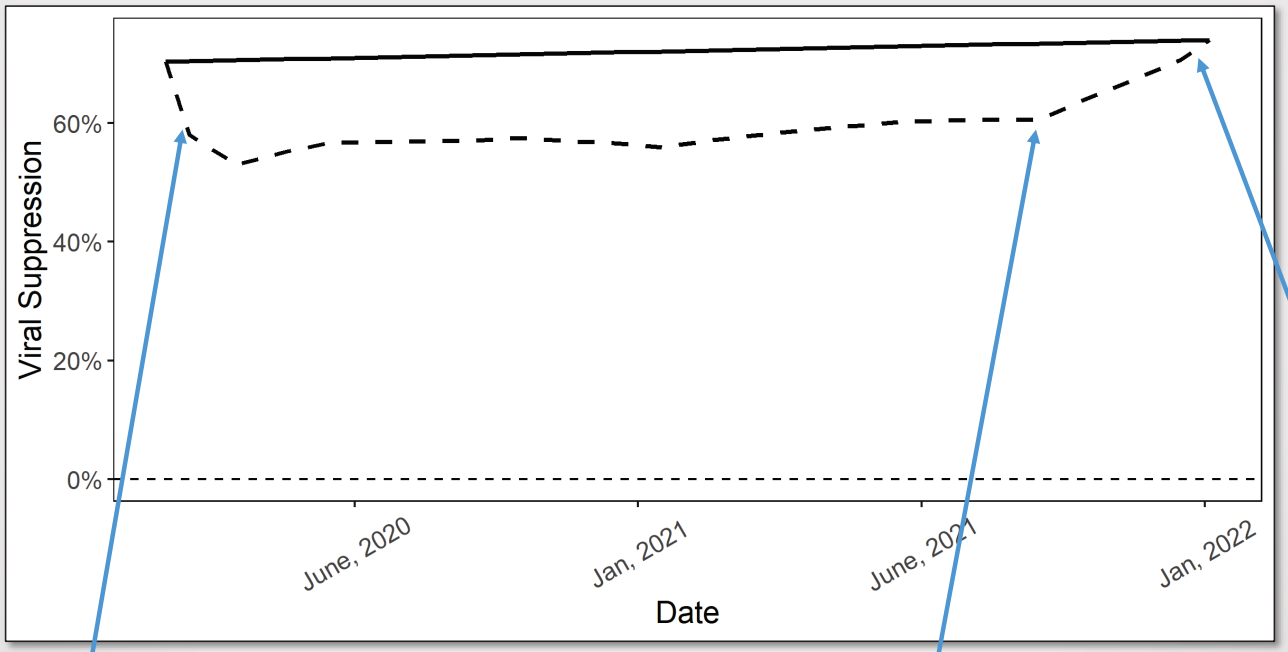
Back to normal July 4, 2021

25% drop March to April, 2020

Begins to normalize March 8, 2021

The COVID-19 Pandemic

- Example **25%** maximal reduction of **Viral Suppression:**



Back to normal Jan 4, 2021

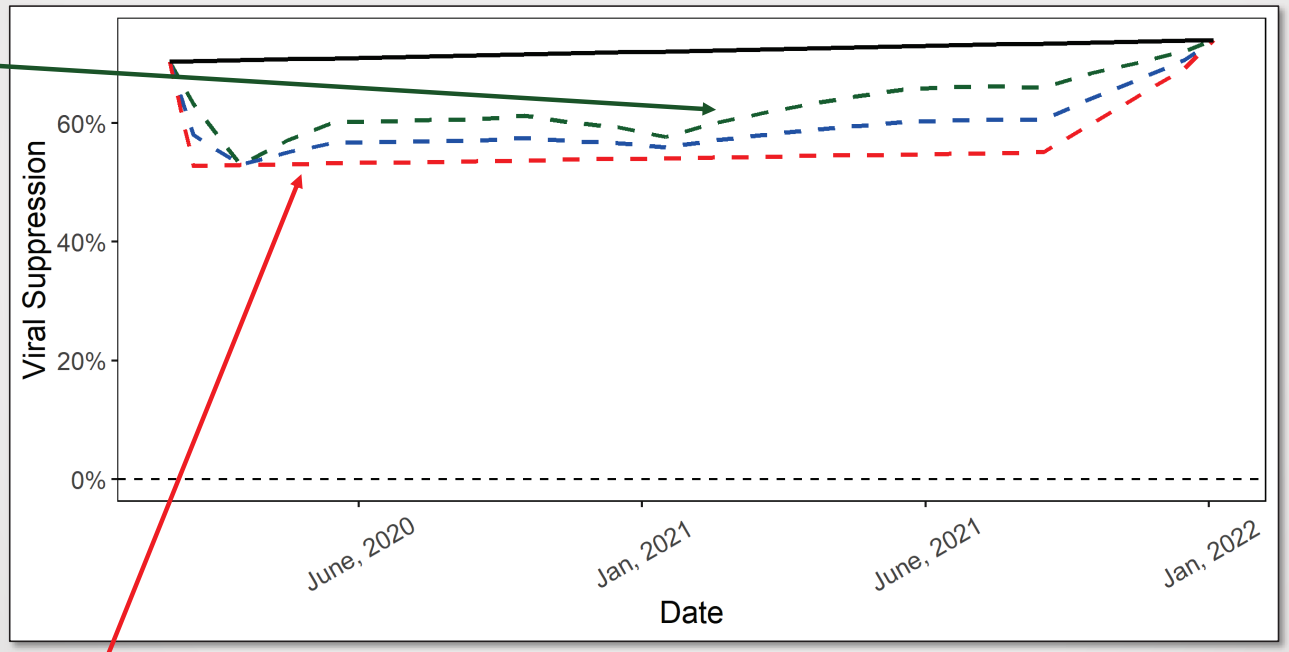
25% drop March to April, 2020

Begins to normalize Sept 8, 2021

The COVID-19 Pandemic

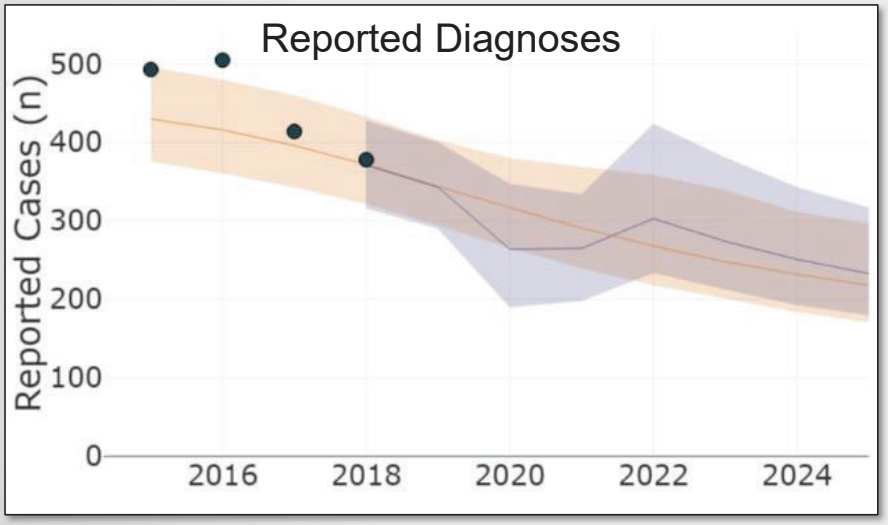
- Different simulations vary how closely HIV parameters track mobility

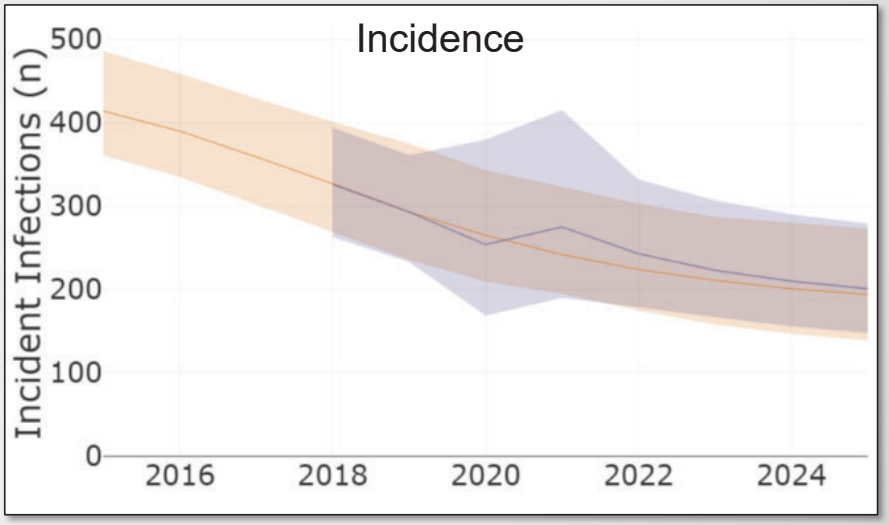
Changes correspond exactly to mobility



Changes are unrelated to mobility

The COVID-19 Pandemic - Projections





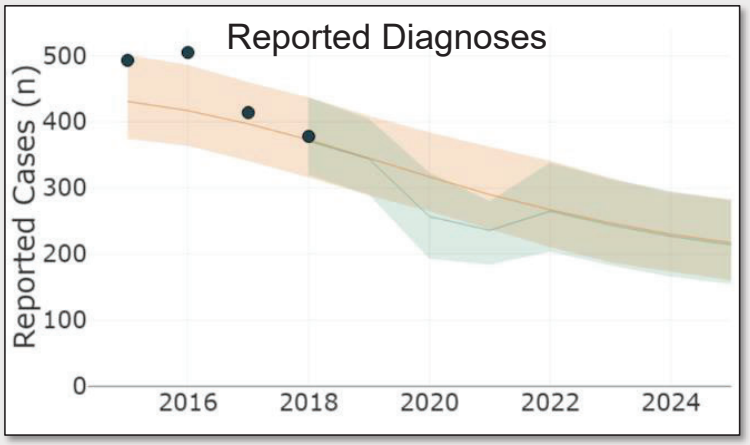
Without COVID: 1,317 cases from 2020-2025
With COVID: 211 (17%) more cases
[35 fewer to 442 more]

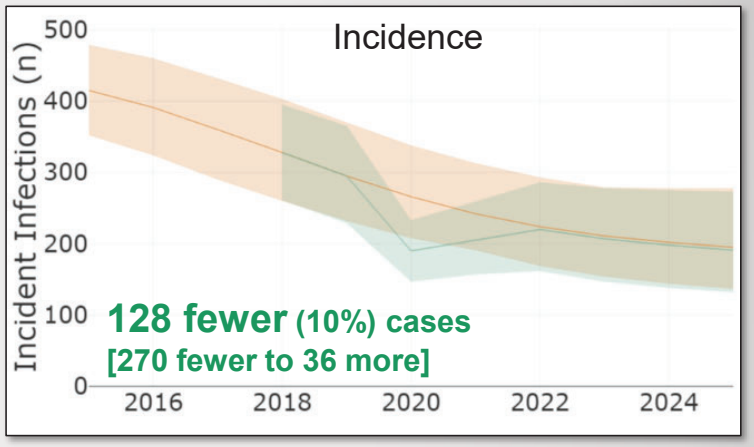
Fojo AT, Wallengren E, Schnure M, Dowdy DW, Shah M, Kasaie P. *Potential Effects of the COVID-19 Pandemic on HIV Transmission: A Modeling Study in 32 US Cities*. Clinical Infectious Diseases. In Press

The COVID-19 Pandemic - Projections

Sexual transmission:
30-50% reduction

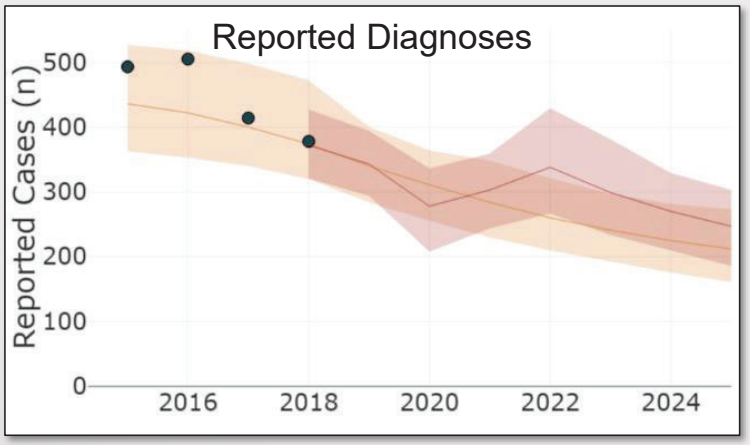
Viral Suppression:
0-15% reduction

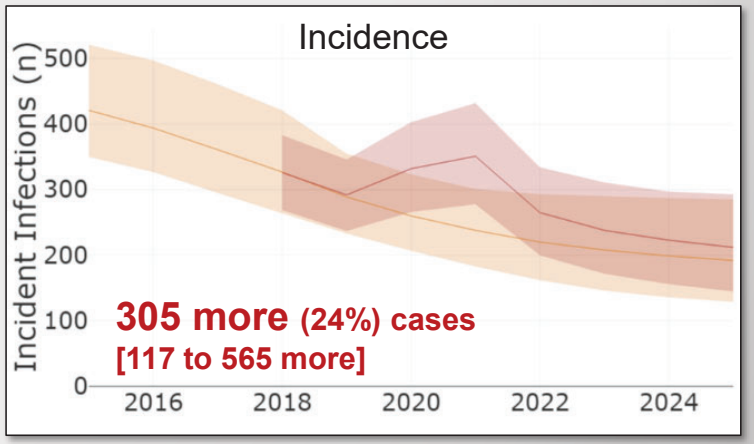




Sexual transmission:
0-20% reduction

Viral Suppression:
25-40% reduction





Conclusions (COVID)

- The effects of the COVID-19 pandemic will depend on
  - Magnitude and duration of disruptions to continuum of care → MORE HIV
  - Magnitude and duration of reduced sexual transmission → LESS HIV
- Traditional HIV reporting is unlikely to accurately reflect underlying transmission for the next few years
  - We'll have to look to other epidemiological data

Limitations

- Homogenous within compartments (averages)
- Can't represent detailed sexual/needle-sharing networks
- No compartments for transgender individuals
- Continuum of care is "collapsed"
- Testing, suppression, PrEP are "evenly distributed" in a compartment
  - In real life, might PrEP uptake be correlated with risky behaviors?

Strengths

- Granular representation of the epidemic (at intersection of age, race, sex, risk factor)
- MSA-level estimates reflect local dynamics
- Rigorous (400,000 simulations per MSA) calibration process to handle uncertainty
- Semi-automated process – easy to scale to other cities

Future Directions

- Expand out the HIV continuum of care so we can test specific interventions to improve viral suppression
- Factor in other epi data to handle COVID
- Costing
- State-level models
- Compartments for transgender individuals (pending data?)

Thanks

- Melissa Schnure
- Parastu Kasaie
- David Dowdy
- Maunank Shah

- Joe Flack
- Carolina Fojo

- Johns Hopkins CFAR
- NIH